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Astronomical cycle origin of bedded chert: A middle Triassic bedded chert sequence, Inuyama, Japan

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ABSTRACT

Astronomical forcing is one of the main drivers of climate change, and astronomical cyclicity recorded in sediments provides a clue to understand the dynamics of the global climate system. Bedded cherts consist of rhythmic alternations of chert and shale beds. Although previous studies have hypothesized that the origin of bedded chert is related to astronomical cycles (e.g. Fischer, 1976; Hori et al., 1993), conclusive proof remains elusive. To explore this possibility, we established a continuous, high-resolution lithostratigraphy of middle Triassic bedded chert in Central Japan. The average duration of each chert–shale couplet is 20 kyr, similar to that of the precession cycle. Spectral analysis of a bed number series of thickness variations in chert beds was performed assuming that each chert–shale couplet represents a 20-kyr precession cycle. The results reveal cycles involving approximately 200, 20, 5, and 2–3 beds, corresponding to periodicities of approximately 4000, 400, 100, and 40–60 kyr, respectively. By further assuming that the 20-bed cycle represents a 405-kyr eccentricity cycle of constant and stable periodicity, we converted the bed number series to a time series. Spectral analysis of the time series revealed distinct periodicities of 3600, 117, 97, and 38 kyr, in addition to 405 kyr. Besides 3600 kyr, these periodicities agree well with the 120, 95, and 37 kyr periodicities for eccentricity cycles and the obliquity cycle during the Triassic. Moreover, we detected amplitude modulation of the approximately 100-kyr cycle of thickness variations in chert beds with a 405-kyr periodicity, which may correspond to amplitude modulation of 100-kyr climatic precession cycle with the 405-kyr periodicity. The approximately 3600-kyr periodicity described above and 1800-kyr periodicity manifested as the amplitude modulation of the 405-kyr cycle are correlated to present-day long-term eccentricity cycles of 2400 and 4800 kyr evolved by chaotic behavior of solar planets. Collectively, these similarities in the periodicities of dominant cycles, their hierarchy, and the nature of amplitude modulation of cycles in chert bed thickness with those of astronomical cycles strongly support the hypothesis that the sedimentary rhythm of bedded chert is paced by astronomical cycles, thereby indicating the potential of bedded chert as a template for a Mesozoic cyclostratigraphy.

1. Introduction

Orbital forcing is one of the main drivers of climate change, and orbital cyclicity\ recorded in sediments provides a clue to understanding the dynamics of the Earth surface system. Numerous studies have examined cyclic bedding and its relation to astronomical cycles, primarily on carbonate sequences (e.g., Gilbert, 1895; Fischer, 1991). In contrast, few reports have searched for orbital cycles on bedded chert sequence. Bedded chert consists of centimeter-scale rhythmic alternations of chert and shale beds. Such chert is widely found in Mesozoic circum-Pacific accretionary complexes, and is considered to have accumulated in a pelagic deep-sea environment (Matsuda and Isozaki, 1991). Numerous hypotheses have been proposed for the origin of bedded chert and its sedimentary rhythms (for details, see Hori et al., 1993; McBride and Folk, 1979). Hori et al. (1993) suggested that bedded chert forms as a result of cyclic changes in the accumulation rate of biogenic SiO_2 within a background of extremely slow accumulation of pelagic clay, based on the 10–100 times higher abundance of magnetic microspheules of probable extraterrestrial origin in shale than in chert. In contrast, Tada (1991) raised the possibility that cyclic changes in Si content within bedded chert are enhanced by diagenetic segregation, whereby SiO_2 is exported from layers with low Si content to those with high Si contents during the silica phase transformation from opal-CT to quartz.

Several studies have suggested that the astronomical cycle origin of the sedimentary rhythm of bedded chert (e.g., Fischer, 1976; Hori et al., 1993; Sugiyama et al., 1994). Hori et al. (1993) proposed that individual chert–shale couplets within Mesozoic (upper Triassic to lower Jurassic) bedded chert in the Inuyama area of Japan may represent astronomical cycles, as the average duration represented by each couplet is 10–70 kyr, with median durations of 20 kyr for the upper Triassic and 40 kyr for the lower Jurassic; these values roughly agree with the periodicities of the

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precession and obliquity cycles, respectively. However, this agreement between the average duration of a chert–shale couplet and one of the periodicities of Milankovitch cycles is insufficient to demonstrate an origin related to astronomical cycles (e.g., Fischer, 1991). Sugiyama et al. (1994) examined temporal variations in the thicknesses of individual chert and shale beds in a middle Triassic bedded chert sequence in the Inuyama area, and detected approximately 40- and 100-kyr periodicities, respectively, using the maximum entropy method and assuming that sedimentation rates were constant within cherts and shale, respectively, and multi-regressed to best fit the age model derived from the radiolarian stratigraphy. This method is similar to the γ-method proposed by Kominz and Bond (1990), although Sugiyama et al. (1994) did not evaluate the statistical significance of their results. In addition, their assumption of constant sedimentation rates for chert and shale may be invalid because the sedimentary rhythm of bedded chert may have been originated from changes in the flux of biogenic SiO_2 (Hori et al., 1993).

In general, an agreement between the periodicities and phases of Milankovitch cycles and of Cenozoic sedimentary rhythms is considered to represent strong evidence for a relationship between the two (e.g., Hilgen, 1991). To test for such an agreement requires a precise age model with high temporal resolution, as well as a detailed solution for the astronomical calculation of the Earth's orbital parameters. However, it is difficult to obtain precise, high-resolution age control for stratigraphic sections older than the early Cenozoic (e.g., Hinnov and Ogg, 2007). In addition, uncertainty regarding the astronomical solution of the Earth's orbital parameters increases with age because of gravitational planetary perturbations such as tidal dissipation and chaotic behavior of the inner planets (e.g., Laskar et al., 2004). In this context, the method proposed by Herbert (1992) is recommended for identifying astronomical cycles in Mesozoic bedded limestone and other bedded sedimentary sequences of this age (e.g., Hinnov, 2000). First, the average duration of a sedimentary cycle is calculated to assess the degree of agreement with the average periodicity of the precession (or obliquity) cycle. Second, under the assumption that a single sedimentary cycle corresponds to one precession (or obliquity) cycle, a bed number series of variations in bed thickness is analyzed to examine the hierarchy of cyclicities. Finally, the hierarchy of cyclicities extracted from the sedimentary rhythm is compared with the hierarchy of cyclicities of the amplitude and/or frequency modulation of climatic precession and obliquity cycles to assess the degree of agreement between the two.

In this study, we adopted the method of Herbert (1992) to test the hypothesis that the sedimentary rhythm of bedded chert is paced by astronomical cycles. To this end, we first reconstructed a continuous sequence of middle Triassic bedded chert in the Inuyama area, Central Japan. We then measured the thickness of individual chert and shale beds throughout the sequence. Herbert's (1992) method was used to construct a bed number series of variations in chert bed thickness and convert the bed number series to a time series of variations in chert bed thickness tuned by a 405-kyr eccentricity cycle of constant duration. In addition, we examined the nature of amplitude and frequency modulations of the dominant cyclicities detected from the bed number series of variations in chert bed thickness, to further test for a relation between the origin of the sedimentary rhythms of bedded chert and astronomical cycles. Based on the results, we discuss the possibility of frequency changes of long-term eccentricity cycles caused by chaotic behavior of the inner planets (e.g., Laskar et al., 2004).

2. Geologic setting

The studied sections are located in the Inuyama area, southwestern part of the Mino Terrane, Central Japan (Fig. 1). The Mino Terrane is a Paleozoic–Mesozoic accretionary complex consisting of greenstone, limestone, bedded chert, and clastic rocks (Wakita, 1988). The accretionary complex in the Inuyama area comprises middle Triassic to lower Jurassic bedded chert and middle Jurassic clastic rocks, which are repeated as tectonic slices (Fig. 1; Yao et al., 1980; Matsuda and Isozaki, 1991). These slices are thrust sheets that were formed during accretion, and are named CH-1, CH-2, CH-3, and CH-4, in structurally ascending order (Yao et al., 1980) (Fig. 1). The bedded chert and clastic rocks are interpreted to have been deposited in a pelagic deep-sea setting below the carbonate compensation depth (CCD) and within a trench at a subduction zone, respectively (Matsuda and Isozaki, 1991). Paleomagnetic analysis of the bedded chert in the study area suggests that the site of deposition changed (as a result of plate motion) from low latitudes in the middle Triassic to middle latitudes in the late Triassic (Shibuya and Sasajima, 1986; Oda and Suzuki, 2000; Ando et al., 2001). Previous studies have compiled a detailed radiolarian biostratigraphy for Triassic to middle Jurassic bedded chert in the area (e.g., Yao et al., 1980; Sugiyama, 1997). However, a continuous, bed-by-bed reconstruction of the Triassic bedded chert sequence has yet to be attempted because of intense deformation and consequent segmentation of the sequence during accretion.

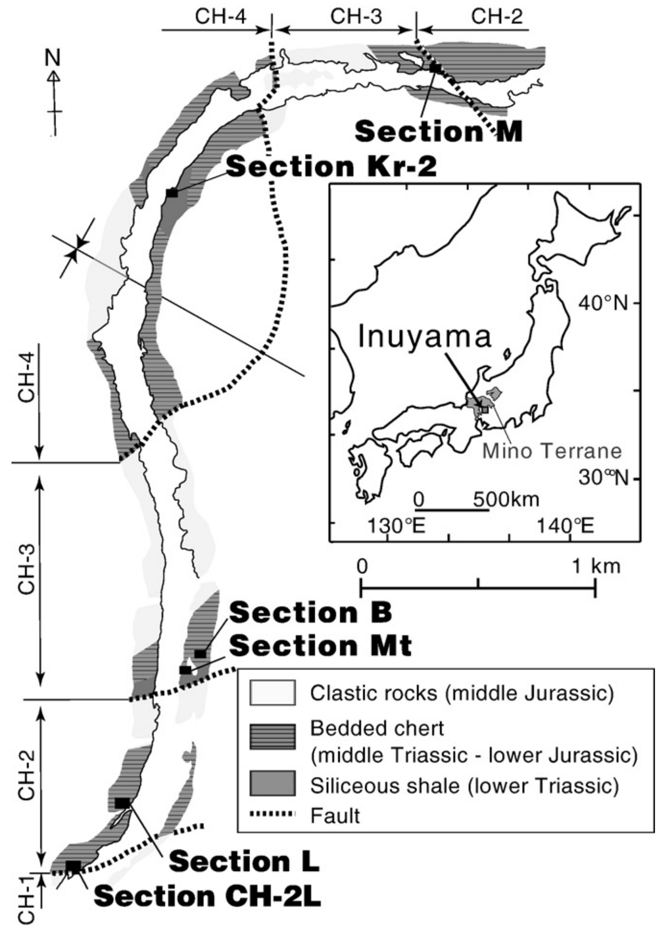

Fig. 1. Location map (inset) and geologic map of the study area (modified from Matsuda and Isozaki, 1991).

To reconstruct a continuous record of the Triassic pelagic sequence in the Inuyama area, we selected six sections for which the radiolarian biostratigraphy has been established. The studied sections are labeled Mt (Spathian to early Anisian; Yao and Kuwahara, 1996), Kr-2 (Spathian to early Anisian; Yao and Kuwahara, 1996), M (early to middle Anisian; Sugiyama, 1997), CH-2L (middle Anisian; Mizutani and Koike, 1982), L (middle Anisian to middle Ladinian; Sugiyama, 1997), and B (late Anisian to early Carnian; Sugiyama, 1997), in ascending stratigraphic order. We conducted detailed geologic